Popocatapetl.

In vol. xli. of Nature, (p. 592) you state: "Despatches from Mexico state that observations show that the height of the active volcano Popocatapetl has decreased by 3000 feet since the last measurement." This despatch, which was forwarded from Prof. Heilprin's party now in Mexico, would seem to indicate that there has recently been an actual *loss* of height in Popocatapetl; whereas Prof. Heilprin's object was to indicate that the observations hitherto accepted are inaccurate.

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295 Adelphi Street, Brooklyn, N.Y.,
May 16.

CHEMICAL CHANGES IN ROCKS UNDER MECHANICAL STRESSES.[1]

After pointing out that his object was to inquire how far the experimental researches of chemists and physicists are capable of affording a satisfactory explanation of the phenomena observed when the rocks of the earth's crust are studied microscopically in thin sections, the lecturer proceeded to give a *résumé* of the experimental investigations of Daubrée, Bunsen, Sorby, Thorpe, Spring, Guthrie, Fouqué, Michel-Lévy, and other chemists, who have devoted their attention to the action of pressure in influencing chemical affinity. The evidence that the deeper-seated rock-masses of the globe, and those constituting mountain-chains, have been subject to enormous pressures was then indicated; and the difference between the statical pressures arising from a great weight of superincumbent rocks, and the dynamical pressures resulting in actual movements within the earth's crust, was insisted upon. The chemical and physical principles which have been established by direct experiment, and which, at the same time, appear to be illustrated by the observations that have been made during recent years upon the minute structure of rocks, and of the minerals composing them, were stated in the following series of propositions:—

I. *In all those cases in which crystallization is accompanied by contraction, the tendency of pressure is to promote the change from an amorphous to a crystalline condition.*

Spring has shown that under a pressure of 6000 atmospheres plastic or amorphous sulphur, having a density of 1·95, passes into rhombic, crystallized sulphur, having a density of 2·05.

The mixtures of silicates which constitute the igneous rocks of the earth's crust all undergo *contraction* in passing from the amorphous (vitreous) to the crystalline condition. This is easily proved by comparing the specific gravities of more or less crystalline rock-masses with that of the glasses formed by their artificial fusion. The experiments of Delesse, Deville, Cossa, and others have shown that mixtures of the silicates of alumina and the alkalies with over 70 per cent. of silica, must undergo a contraction to the extent of $\frac{1}{11}$ of their bulk in passing from a glassy to a highly crystalline state (granite). Mixtures of the silicates of alumina, magnesia, iron, lime, and the alkalies with less than 50 per cent. of silica, in passing from a vitreous state to a perfectly crystalline one (gabbro), must undergo a reduction in bulk equal to $\frac{1}{7}$.

It may fairly be anticipated, therefore, that great pressure would tend to promote the crystallization of the mixtures of silicates composing most of the rocks of our globe, or to prevent their assuming the glassy state; and a great body of geological facts tends to support this conclusion. It must not, of course, be lost sight of that slow consolidation is also favourable to the process of crystallization, and rocks being extremely bad conductors, the process of cooling in great rock-masses is excessively slow. It is often difficult therefore to discriminate between the effects that must be referred to slowness of cooling, and those which may be safely considered to result from pressure.

As long ago as 1846, Charles Darwin showed that the andesitic lavas of the Cordillera of South America are associated with perfectly crystalline rock, true granites, made up of precisely the same minerals. The identity of the minerals in the plutonic rocks and the lavas respectively was demonstrated by the careful studies of Darwin himself, and of Prof. W. H. Miller, of Cambridge, long before the method of studying rocks in thin sections had been invented. Quite recently Prof. A. Stelzner, employing the modern methods of research, has been able to completely confirm the interesting results arrived at by Darwin and Miller, and to show that a perfect gradation can be traced between the highly crystalline "Andengranites," and the more or less glassy lavas (andesites) which are so closely associated with them.

In 1874 I was able to show that in the Western Isles of Scotland there occurred masses of perfectly crystalline (granitic) rock, identified by Zirkel as true gabbros and granites, which can be traced passing by the most insensible gradations into natural glasses ("tachylytes" and "obsidians") (Quart. Journ. Geol. Soc., xxx., 1874, 233–48), and the truth of these conclusions has been fully established by the more recent researches of Dr. A. Geikie (Trans. Roy. Soc. Edinb., 1888, 122–24, 145–50). In 1876 I further showed that the diorites and quartz-diorites of Hungary and Transylvania pass insensibly into the ordinary lavas of the district, which have the same ultimate chemical composition, and the same mineralogical constitution (Quart. Journ. Geol. Soc., xxxii., 1876, 292). In 1885, Messrs. Arnold, Hague, and J. P. Iddings, of the United States Geological Survey, established precisely similar conclusions by the study of rocks in the Nevada district (Bull. U.S. Geol. Surv., No. 17, 1885); and Signor B. Lotti, of the Italian Geological Survey, in the following year proved the same to be true in the case of the rocks of Elba.

In all these cases it is seen that the masses which have been most deeply seated, and thus subjected to the greatest statical pressures, are those which have undergone the most perfect crystallization. It must of course be remembered that in these cases the other cause tending to the development of crystalline structure comes into play—namely, slowness of cooling. The ordinary materials of igneous rocks are such bad conductors of heat, that enormous periods of time must elapse before the deeply seated portions of igneous rock-masses can become solidified.

The potent influence of this extreme slowness of cooling in bringing about the crystalline structure in molten masses of silicates has been well illustrated by the splendid researches on rock-synthesis by MM. Fouqué and A. Michel-Lévy. They have shown that the secret of making a particular mineral crystallize out of such a mass consists in finding out the temperature of fusion of the mineral, and in maintaining the molten mass for a long period just below this temperature. In the excessively slow cooling of deeply seated rock-masses, the materials must be kept successively and for long periods at temperatures a little below the fusion-points of each of their mineral constituents.

But while the influence of slow cooling in producing the crystalline structure in rocks is unquestionably very great, the effect of pressure in promoting crystallization can scarcely be doubted. We have no proof, indeed, that the holocrystalline or perfectly granitic structure of rocks can ever be produced except under these conditions of extreme pressure.

II. *Crystallized minerals, developed in a magma under pressure, may lose their stability and be dissolved by the same magma when the pressure is removed.*

The very remarkable researches of Fouqué and Michel-

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[1] "The Evidence afforded by Petrographical Research of the Occurrence of Chemical Change under Great Pressure." A Lecture delivered before the Chemical Society, March 20, 1890, by Prof. J. W. Judd, F.R.S.

Lévy upon the synthesis of rocks is not less instructive, whether we consider the successes or the failures of their experiments. While able to reproduce by fusion and slow cooling—either from the powdered rocks themselves, or from duly admixed proportions of silica, alumina, iron oxide, and the alkaline earths and alkalies—various kinds of basalts and other basic rocks, all attempts to form certain other rocks, especially those containing quartz, hornblende, and muscovite, failed. The conclusion at which the experimenters arrive—and the correctness of this conclusion it is scarcely possible to doubt—is that, for the formation of such minerals and of the rocks containing them, water and other volatile substances, held within the solid mass by intense pressure, is absolutely indispensable.

Now in the porphyritic constituents (*Einsprenlinge* or phenocrysts) of many lavas, we find examples of minerals which have been formed at great depths in the earth's crust and then brought up to the surface and exposed to totally different conditions, especially as regards pressure. Very clearly do these phenocrysts tell the tale of their origin, and of the influence exerted upon them by their subsequent environments.

Crystals of quartz and felspar, which have grown to large proportions in the deeper portions of the earth's crust, are found when brought up in lavas to the earth's surface, and thus relieved from the action of pressure, to be attacked by the magma in which they were originally formed. The proof of this is seen in the corroded condition of the crystals, the glassy matter surrounding them having attacked their angles, their edges, and in a less degree their whole surface, penetrating irregularly into their interior, and reducing them sometimes to mere skeletons.

Crystals of hornblende and mica betray in an even more striking manner the effects of a change of environment. When brought up from great depths in masses of molten lava, crystals of these minerals are constantly found to be surrounded by "resorption halos." The outside of the hornblende or mica crystals, where in contact with the molten glass, is found to be attacked by it, and crystals of pyroxene and magnetite have resulted from the reaction. The action may in some cases continue till the whole of the hornblende has been converted into a pseudomorph.

In some instances there may be reason to believe that the phenocrysts have become enveloped in a magma of different chemical composition to that in which they were originally formed. But in many cases there is no room for doubt that the minerals which were formed and maintained their stability under certain conditions of pressure, lost that stability upon the diminution of pressure.

That, conversely, the increase of pressure leads to the production of a condition of instability in minerals formed at or near the earth's surface there cannot be any doubt. The study of the formation of crystalline schists from various aqueous and igneous rocks supplies us with numerous and very interesting illustrations of changes of this kind: hornblendes, chlorites, micas, and talc are produced under conditions of pressure in which pyroxenes, epidotes, felspars, and olivines lose their stability.

III. *In all those cases where solution is attended by contraction, the solvent action of water and other liquids is increased by pressure.*

That this is the case at elevated temperatures is proved by the researches of Daubrée to which we have already referred. Pure water was made to attack various silicates quite insoluble at ordinary temperatures and pressures. Even if we admit with Bunsen that there are temperatures at which this influence of pressure is no longer operative, or at which the effects are wholly inappreciable, the admission would not in any way affect the theoretical views of the geologist, seeing that the increase of temperature within the earth's crust is so rapid, that even at moderate depths the temperature at which solvent action is increased by pressure must certainly exist.

The *effects* of this solvent action under pressure are everywhere manifest when we come to the study of the rocks building up our earth's crust. At more or less considerable depths, water containing carbon dioxide has attacked the silicates composing the rock-forming minerals; so that it is impossible to find rocks which have been deep-seated, at any period of their history, in which the minerals are in a perfectly unchanged condition.

Great masses composed originally of calcic carbonate, are found to have been changed into dolomite (the magneso-calcic carbonate), or into chalybite (the ferrous carbonate); while in other cases the whole mass of a bed of calcic carbonate has been dissolved away, and silica substituted as a "pseudomorph."

We must proceed to study the details of such processes especially as they are affected by pressure and by the crystalline structure of the minerals affected.

IV. *Under great statical pressures, the whole substance of solid bodies may be permeated by fluids, and chemical reactions between them are thus greatly facilitated.*

It is not necessary to point out that the molecules of the densest solids cannot be in actual contact; this is proved by the circumstance that such solids undergo contraction by lowering of temperature, and that gases may be occluded in them. Physicists and mathematicians, as recently pointed out to this Society by Prof. Rücker, have even been able to arrive at positive conclusions concerning, not only the actual order of magnitude of molecules, but the *distances* that separate them from one another in solids.

The effect of pressure in causing the molecules of one body to pass between those of another, has been expressed by Van der Waals in the dictum, "All bodies can mix with one another, when the pressure exceeds a certain value." A similar conclusion was expressed by the late Dr. Guthrie, as the result of his experiments on potassic nitrate, when he asserted that "fused nitre and fused ice are miscible in all proportions."

Now, nothing is more certain, from petrographical researches, than that the whole substance of the minerals in the deep-seated rock-masses of the globe may be permeated by fluids. This is shown by the condition of the minerals forming these deep-seated masses.

The felspars, in their normal condition, are colourless and transparent minerals with a vitreous lustre, and this is their character when they are found in lavas and in blocks ejected from volcanoes. In granites and other deep-seated rocks, however, these same felspars exhibit grey, green, pink, or red tints, with more or less opacity, and a remarkably pearly lustre. The cause of this change of aspect is found in the fact that the unstable alkaline silicates which enter into their composition have been attacked by the fluids that have penetrated through the whole substance of the crystal, leading to the formation of the hydrated silicates of alumina, and, in some cases, the peroxidation of any traces of iron compounds that may have been present in them.

Similar changes can be shown to have affected most, if not all, the minerals which, at any period of their history have formed portions of deep-seated rock-masses.

V. *By the intimate intermixture, under great statical pressures, of solids and fluids, the properties of the former undergo great modifications.*

Bunsen, in common with all chemists who have studied the great problem of geology, has insisted that fused silicates, in spite of the high temperatures at which they assume the fluid state, obey the same laws as those governing ordinary solutions. Guthrie has shown that the principles which determine the formation of "cryohydrates" and of "eutectic compounds" are equally operative in the case of the separation of minerals from a mixture of fused silicates; and the same idea has been elaborated by Lagorio. Guthrie has further shown that, as water is added to a salt, the fusion-point of the mixture is progressively lowered, and from this fact he concludes that "the phenomenon of fusion is nothing more than an extreme case of liquefaction by solution."

That silicates, when they are mixed with water, fuse at a lower temperature, was long ago recognized by geologists—long, indeed, before any physical explanation had been offered of the fact. Poulett-Scrope, Scheerer, Elie de Beaumont, Daubrée, and many others who might be mentioned, have insisted on the important part played by water in promoting the fusion of lavas and other igneous masses.

In the case of the volcanic glass known as *marekanite*, I have shown that at a comparatively low temperature the mass will, when heated, swell up and intumesce, the escaping steam causing the molten glass to froth up and assume the character of a true pumice (*Geol. Mag.*, Dec. 3, iii. 243). The brown glass ejected from Krakataö, during the great eruption of 1883, if heated, increases to many times its original bulk, and passes into a substance which, macroscopically and microscopically, is indistinguishable from the pumice thrown out in such vast quantities during that great eruption (*Geol. Mag.*, Dec. 3, v. 6).

Many volcanic glasses contain an appreciable quantity of water, amounting in some cases, indeed, to as much as 10 per cent. of their mass. The glasses which contain water fuse at a lower temperature than those which are anhydrous. There is reason to believe that most lavas are not masses in a state of simple fusion, but consist of crystals floating in a mass of mixed silicates and water, the magma being at a temperature above the fusion-point of the mixture but below that of the crystals.

VI. *Mechanical stresses, which tend to overcome the attraction between the particles of a solid, promote chemical action at those parts of its mass which are in a condition of intense strain.*

That a direct relation exists between mechanical and chemical forces is shown by the fact that capillary action is capable of overcoming weak chemical affinities. Violent mechanical shocks will sometimes completely overmaster chemical affinity, as was shown by Berthelot in the case of acetylene, cyanogen, &c., and more recently by Prof. Thorpe in the case of carbon disulphide.

Carnelley and Schlerchmann endeavoured to show that the solution of a copper wire by acid was promoted when the wire was put into a condition of strain. These experiments, it is true, yielded negative results, a circumstance which is, perhaps, hardly to be wondered at, when we remember how feeble were the mechanical forces employed.

In the case of the curiously impressed limestone pebbles of the Swiss Nagelflue, however, Sorby has shown that there are grounds for believing that solution is promoted in masses which are subjected to intense mechanical stresses, and he has confirmed this conclusion by an ingenious experiment with rock-salt (Yorksh. Proc. Geol. Soc., iv. 458–61).

Similarly impressed and faulted pebbles from the Old Red Sandstone of Stonehaven, in Scotland, have afforded what I think is indisputable evidence of the action of strain in promoting solution. The sand-grains, of which these pebbles are composed, are seen under the microscope to be traversed by bands of liquid enclosures that are clearly of *secondary* origin. Now, these bands of enclosures are parallel to the actual faults that have been produced in the pebbles, and the careful study of all the facts renders inevitable the conclusion that when the whole mass, under great statical pressures, was permeated by fluids, solvent action was determined in parts of the mass subjected to violent strain (*Mineralogical Magazine*, vii. 83).

Similar bands of secondary liquid inclusions, which have clearly been produced in the same way, abound in the crystals of many rock-masses that have been subjected to strain and movement.

VII. *Pressure may supply the conditions required for the renewal of the growth of crystals when their development has been arrested for an indefinite period, and even after they have suffered mechanical injuries.*

In 1856, Louis Pasteur published the results of his interesting investigations upon the property exhibited by bimalate of ammonia and other salts, the crystals of which are able to repair injuries produced by fracture; and this experiment has been repeated and confirmed by Scharff and other observers.

This principle of the growth and repair of injured crystals is one of great importance and wide application in geological investigation. Sorby has shown that rounded and water-worn sand-grains that have originally constituted a portion of granite or other igneous rock may, in the presence of solutions of silica and under pressure, renew their growth, and, in the end, acquire the faces and angles characteristic of quartz-crystals The observations of Becke, R. Irving, Van Hise, Bonney, and other microscopists have shown that, not only fragments of quartz, but portions of the crystals of felspar, augite, hornblende, biotite, and other minerals, may undergo enlargement in a similar way. It has further been shown that this repairing and growth of crystals is continually taking place in rocks under pressure; that the composition of the outer parts of a crystal may vary as growth goes on; and that the action can take place in solid rock-masses (Quart. Journ, Geol. Soc., xlv. 175–86).

I have found it possible to illustrate experimentally some of the phenomena exhibited by zoned crystals in rocks. An octahedral crystal of chrome-alum of a dark-purple colour was mutilated by having two opposite solid angles broken off from it and then placed in a solution of common ammonia-alum (see Fig. 1). By more rapid growth in the injured portions, the crystal tended to repair itself, but the regularity of this process was interfered with by subjecting the crystal and solution to a somewhat wide range of temperature. As the coefficient of expansion of chrome-alum appears to be different from that of ammonia-alum, the shell of the latter material

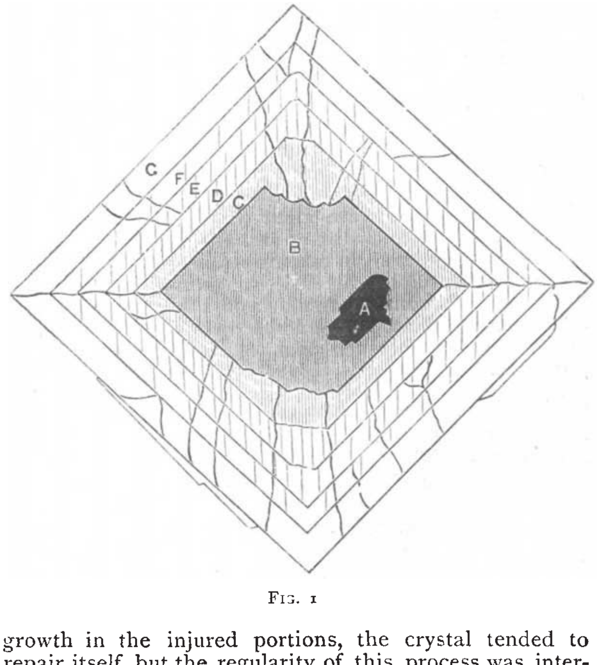

FIG. 1

was from time to time cracked by the unequal expansion. The solvent, finding its way into the interior, partially dissolved away the original crystal of chrome-alum. The final result of these changes was that while the form of the alum octahedron was almost completely reproduced, only a small portion (A) of the original chrome-alum crystal remained. Much of the chrome-alum was dissolved out and replaced by a mixture of the two alums (B), while the other layers of the crystal (C, D, E, F, G) were formed by still paler-coloured zones, also consisting of mixtures of a like kind. Zoned crystals exhibiting similar abnormal appearances to this alum crystal are by no means rare in some igneous rocks.

VIII. *When solution under pressure is going on in a crystalline body, the action is controlled and modified by its molecular structure. This molecular structure may have been produced either in the process of crystallization, or as the result of mechanical or other forces acting upon the crystal subsequently to its formation.*

Daniell's earliest contributions to science, in the year 1816, dealt with the remarkable and unequal action of solvents upon crystals. The curious and complicated patterns produced on the faces and the cleavage or cut surfaces of crystals (etching-figures) have subsequently been studied by Leydolt, Klocke, Baumhauer, Becke, and other investigators. The results obtained have been shown to vary with the nature and strength of the solvent, the temperature, the pressure, and the time during which the action is allowed to take place.

In 1884–85, Von Ebner, as the result of an exhaustive study of the etching-figures of calcite and aragonite, showed that crystals possess *planes of chemical weakness*, to which he gave the name of "solution-planes," these being analogous to the well-known planes of least cohesion or cleavage-planes. Quite independently, I, about the same time, arrived at the same conclusion by studying the crystals in deep-seated rocks (Quart. Journ. Geol. Soc., xli. 383, &c.). In these deep-seated rocks the crystals (their whole substance being permeated by the solvent) yield to chemical action along their solution-planes, along which hollow spaces in the form of negative crystals are produced.

When twinning-planes are developed in crystals by pressure or other mechanical agencies, these planes (gliding-planes) become planes of chemical weakness (*Mineralog. Mag.*, vii. 87). The experiments of Reusch, Baumhauer, Mügge, Foerstner, and others have shown how frequently this secondary twinning is developed in the crystals of rock-forming minerals.

When the negative crystals formed along the solution-planes of a mineral are filled with various secondary products, the whole character and aspect of the substance may be transformed. When the infilled negative crystals are of appreciable dimensions, the avanturine and "schiller" phenomena result from the action. When the action is on an ultra-microscopical scale, the phenomena of opalescence and of iridescence may be produced.

By the introduction of various substances in solution into a crystal, its composition may be altered and the way prepared for the recrystallization of the substance as a distinct mineral. It has been shown that, by the introduction of sodic chloride into a plagioclase-felspar, the way has been prepared for the conversion of that mineral into scapolite (*Mineralog. Mag.*, viii. 186).

IX. *Under great pressures, paramorphic changes take place in crystalline bodies without any alteration in their chemical composition.*

It is a well-known fact that, under the slight pressure which can be exerted by the hand, the orthorhombic, yellow variety of mercuric iodide passes into the tetragonal, red variety. Spring has shown that, under a pressure of 5000 atmospheres, monoclinic sulphur passes, at ordinary temperatures, into the orthorhombic form. Van 't Hoff and Reicher have shown that the temperature at which this latter change takes place is progressively diminished as the pressure is increased.

That slight forces acting through a considerable period of time are competent to produce such paramorphic changes has long been known. Thus the mercuric iodide and sulphur undergo their paramorphic changes slowly when subjected only to the ordinary vicissitudes of atmospheric temperature.

Many interesting examples of similar heteromorphous forms of the same compound are familiar to geologists, such as calcite and aragonite among the carbonates, and pyroxenes and amphiboles among the silicates. Heteromorphism, indeed, appears to be the rule rather than the exception in the mineral kingdom.

The slow paramorphic changes between heteromorphous forms of the same compound was long ago studied by Gustav Rose; and in more recent years the dependence of these changes on great pressures, or on small forces acting through long periods of time, has engaged the attention of J. A. Phillips, Allport, Hawes, R. D. Irving, J. Lehmann, G. H. Williams, Teall, and other observers.

In considering these paramorphic changes, it must be remembered that the transition under pressure is not always, as in the case of sulphur, from a less dense to a more dense form. On the contrary, as in the change of both aragonite to calcite and of augite to hornblende, we find the denser but less stable form passing into the less dense but more stable one. Stability, however, is only a relative term: while one form of a compound may be most stable at one temperature or under a certain pressure, other conditions may exist under which it becomes an unstable form.

X. *Both solution and the formation of new crystalline compounds may result from pressure, and these two operations may take place together; in this way more or less complete interchange of ingredients may take place between the crystalline bodies, and pseudomorphs be formed.*

That most of the pseudomorphic changes, so common in the mineral kingdom, take place at considerable depths from the surface there seems no room to doubt; and in all these cases it may be inferred that pressure is one of the determining conditions of the action.

The effects of these pseudomorphic changes in transforming vast rock-masses into others of totally different composition—such as limestone into dolomite, chalybite, or silica—has long been familiar to geologists; and modern microscopical methods have enabled us to trace the progress of these changes from their earliest beginnings to their complete consummation.

Without entering further into this very wide question, I may mention that Mr. G. F. Becker has lately published the full details of his studies of the Coast-Ranges of California, and that these tend to prove that, in comparatively recent geological times, vast masses of rock in that district have had their substance replaced in some cases by silica, and in others by serpentine; the changes sometimes taking place over considerable areas. These conclusions, arrived at by the officers of the U.S. Geological Survey, if fully established—and there appears to be no room for doubt as to their general accuracy—are not less interesting and suggestive than they are novel and startling.

XI. *When, as the result of dynamical pressures, the crystalline constituents of rocks are brought into close contact, chemical affinity comes into play between them, and new mineral species result from the reactions that take place. This operation is facilitated, when, as a consequence of internal strains, differential movements are set up within the rock-mass, and rubbing or sliding contacts between its particles are brought about.*

Chemists are acquainted with many examples of chemical action following from the simple bringing into close contact of molecules. In the union of gases, when they are condensed by platinum-black, and even in the light rubbing of a safety-match on the match-box, we have illustrations of such phenomena.

Spring has shown that, when powdered metals are mixed together and subjected to great pressures, union takes place between them, and alloys are formed. When dry anhydrous salts are similarly treated, double decomposition takes place, and new compounds are formed.

Prof. Thorpe has shown that dry anhydrous salts may be made to react with one another by being simply rubbed together in a mortar; and both Mr. Hallock and Prof. Spring are agreed as to the intensification of action which occurs when rubbing or sliding movements—attended with necessary multiplication of points of contact in compressed bodies—takes place.

Lastly, it may be pointed out that Spring has recently shown *time* to be a very important factor in such changes, by allowing slow diffusion to take place at the surfaces of contact.

That the rocks known as "crystalline schists and gneisses" have had their peculiar characters produced by "internal differential movements," resulting from "enormous irregular pressures," was clearly recognized by Poulett-Scrope, Darwin, Naumann, and Sharpe long before the researches of physicists and chemists had supplied us with the explanation of the phenomena. Modern petrography has confirmed and illustrated these conclusions, enabling us to study the actual stages of the processes of change by which, through the reaction of the constituent minerals of a rock under pressure, the whole mass resolves itself into a completely different mineral-aggregate. The labours of Lossen in the Hartz, of J. Lehmann in Saxony, and of H. Reusch in Norway, have been of especial value in establishing these important conclusions.

As an illustration of this kind of action, we cannot, perhaps, do better than take the case of a rock (gabbro) consisting of three somewhat unstable constituents (see Fig. 2), labradorite (A), pyroxene (B), and olivine (C). In the rock from which the figure has been taken, there are clear evidences of its having been subjected to deforming stresses. Where the olivine, the least stable of the three minerals, is in contact with the labradorite, the silicates of which they are composed have reacted upon one another. The result is seen in the formation of a zone between them, consisting of entirely new minerals—a pyroxene (D), and a hornblende (E). Similar changes, but not so strongly marked, are seen to be in progress between the olivine and the pyroxene, and between the pyroxene and the labradorite.

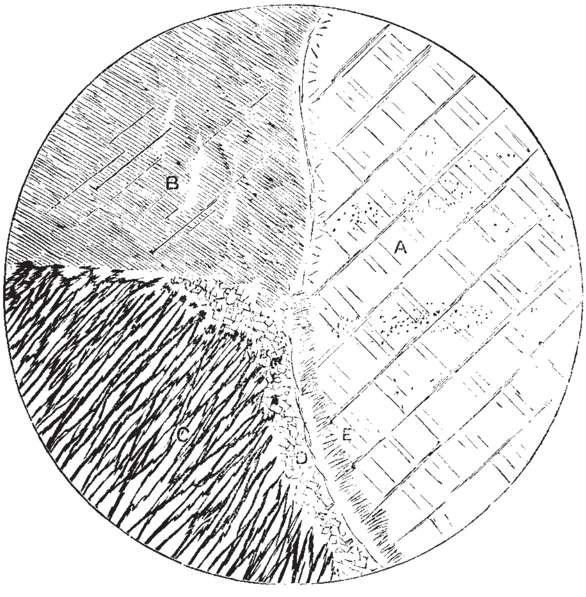

Fig. 2.

By carefully selecting and studying a series of specimens from the same rock-mass, every step in the metamorphosis of a rock may be followed, from incipient changes like those in the case above illustrated, to the final disappearance of every vestige of the original mineral constituents of the rock, and the substitution of new mineral species.

XII. *When internal strains and differential movements affect a mass, which is at the same time undergoing recrystallization, the forms and relations of the crystalline particles that build up the new rock may be greatly modified by the action of the mechanical forces.*

That perfect rest is a condition upon which well-developed crystallization depends, is a fact too well known to need dwelling upon here. That very small mechanical causes, such as the presence of foreign bodies, or the existence of rough surfaces, may determine the size and position of crystals in a solidifying mass, is also a fact familiar to every chemist. By stirring or similar movements carried on within a crystallizing mass, granulation, or the formation of a number of small imperfect crystals, rather than of large and well-developed ones, is brought about; as in the well-known Pattison's process for desilverizing lead.

The evidence of perfectly similar actions having taken place in crystallizing rock-masses is everywhere conspicuous; and the results are the same, whether the crystallization occurred in a mass passing from a fluid to a solid state, or in a mass which remained solid during the whole process of recrystallization.

There are two structures which are especially exhibited by rocks that have been subjected to dynamo-metamorphism which seem clearly to have been produced by such causes; these are the structures known as the *granulitic* and the *foliated*.

The *granulitic* structure, which is so well exhibited by the rocks called "granulites," is characterized by the crystals assuming the form of granules, having more or less rounded outlines, and lying in every position; so that, under the polariscope, the mass resembles a fine mosaic. I have shown that well crystalline rock-masses (gabbros), when forced in a molten state through great fissures, assume on their edges, where much friction must have occurred, this granulitic habit, which is sometimes exhibited in a very striking manner (Quart. Journ. Geol. Soc., xlii. 76, &c.).

The foliated structure, so characteristic of schists and gneisses, consists in the separation along nearly parallel planes of leaf-like patches (folia) of the several mineral constituents of the crystallizing mass. Poulett-Scrope, from his study of the viscous lavas of Ponza, Lipari, and Hungary, and Darwin, from his study of the similar lavas of Ascension, were able to show that these rocks, under similar conditions, often assume a *foliated* structure. Perfectly granitic rock-masses, like the syenite of the Plauenschen Grund and the granitite of Aberdeen, sometimes exhibit on their margins a distinctly foliated structure.

It is worthy of notice that both the granulated and the foliated structures are produced in recrystallizing masses that are subjected to internal strains and differential movements. They are equally produced when the mass has been a liquid which has slowly passed into the solid state by the process of crystallization; and when by the processes we have already considered the mass, *retaining its solidity*, has undergone internal molecular rearrangement and recrystallization.

A rock-mass behaves as a viscous body, under slight pressures, when heat and the presence of water have overcome the cohesion of its particles. But the researches of Tresca and Daubrée have shown that, when subjected to sufficiently powerful stresses, the most perfectly solid bodies we know of behave like viscous bodies, and can be made to *flow*

In the foregoing remarks, my main object has been to show how far the physical and chemical principles, which have been established by actual experiment, are capable of explaining the phenomena observed by the geologist in studying the earth's crust. I have especially avoided invoking any causes which must be regarded as hypothetical.

Some of the actions relied upon as explaining the origin of the great features of the rock-masses which compose the earth's crust may seem at first sight small and even insignificant. But the great lesson taught by modern geological science is that such small forces, operating upon enormous masses of matter during vast periods of time, are capable of effecting the most stupendous results.

In speaking of *statical* pressure, I have not treated it as an agent of change, like heat or electricity, but simply as a condition under which these agents operate—one which may profoundly modify or control their action. Such pressure, too, may produce great effects by causing a closer contact and consequent chemical action between the molecules of a fluid made to penetrate a solid, or between the molecules of two solids forced into more perfect contact. Statical pressure may, further, prevent the escape of volatile materials even under extreme temperatures, and these substances, as in the case of the "mineralizers" of the French chemists, may exercise important influences on the solids or liquids within which they are retained.

Dynamical pressure, especially when it results in differential movements in a mass, can certainly do all that is effected by statical pressure, and perhaps something more. That such motion is converted into heat there can be no doubt; and some geologists, like the late R. Mallet and Prof. Prestwich, have argued that the heat so produced must have played an important part in the work of metamorphism. But considering the slowness with which the earth-movements have probably taken place, and the opportunities for the dissipation of this thermal energy, it may be regarded as at least doubtful if at a particular point in the rock-mass the temperature could ever have been raised to such an extent, that any very important part of the work of metamorphism ought to be ascribed to it. In the same way, we may, perhaps, regard the suggestion of Mr. Sorby that, during great earth-movements, mechanical energy is directly converted into chemical energy, as one in favour of which no convincing evidence has as yet been adduced.

It is at least conceivable that the realm of excessively *high* pressures is one in which phenomena may be displayed which are as anomalous as those exhibited under extremely *low* pressures—the high *vacua* of Mr. Crookes. But until such effects have been demonstrated by actual experiment, it is unwise to invoke their aid in geological hypothesis. My great object, in the remarks I have ventured to offer you this evening, has been to show that, on well-established physical and chemical principles, the phenomena, which are exhibited by rock-masses that have been subjected to great pressures, are capable of satisfactory explanation.

THE UNIFORM PENNY POST.

Of all the jubilees that are now being celebrated, there is none which has had a more beneficial influence on the age than that celebrated last week at the Guildhall, with such success and good management. There are some who deplore the decay of letter-writing, and even a few who regard the penny post as an unmitigated evil, but no one can fail to perceive that the conduct of the great commercial business of this country would have been impossible without cheap postage.

We are not celebrating the penny post. This was proposed in 1659, by one John Hill, an attorney of York—curiously enough a namesake of Sir Rowland's—who showed its practicability and advocated free trade in letter-carrying. He proposed a rate of 1*d.* in England, 2*d.* in Scotland, and 4*d.* in Ireland, as well as 3*d.* per ounce for small parcels.

Nor are we celebrating the invention of adhesive stamps, but the introduction, in 1840, of that great measure which swept away a sliding scale of postage of single letters written on single sheets of paper which varied between 4*d.* and 1*s.*, and a system of franking that had grown, even in the reign of our present Queen, to a most shameful abuse. Envelopes or covers and enclosures involved double postage. If the letter weighed an ounce the rate was quadrupled. A single letter, London to Brighton, cost 8*d.*, to Edinburgh 1*s.* 1½*d.*, to Cork 1*s.* 5*d.*; or if it weighed 1¾ ounces, to Edinburgh 7*s.* 7½*d.*, to Cork 9*s.* 11*d.* The number of letters passing through the post in 1839 was 76,000,000. In 1889, it amounted to 1,600,000,000, and this excludes newspapers, post-cards, books, and parcels. The grand total for 1889 was 2,362,000,000.

It is not too much to say that the transport of this enormous mass of material would have been impossible but for the advent of steam. Railways and steam-boats have led to the possibility of the uniform post. Telegraphs have made its administration practical and simple. Without these practical applications of science its success would have been impossible. Pack-horses, mail-coaches, and sailing-vessels, would have failed to transport mails with the celerity, trustworthiness, and regularity, that are the essentials of a true postal service.

The Stuarts made the Post Office a monopoly of the Crown; and the Commons, who in Charles's day denounced the establishment of the monopoly, promptly proceeded by Cromwell's soldiers to put down John Hill and his free trade in letters. It has remained the monopoly of the State, and its work is well done, but this is due to the fact that it is so well supervised by the public itself, every member of which is interested in its well-working. If the breakfast table is not garnished with the expected letters, if any abuse, want of accommodation, or delay occurs, the press or the House of Commons soon wants to know the reason why, and the remedy is at once applied. In fact, the public is the master and the postal service knows it. In no service in the world can there be found more zeal, energy, and attention. The rewards are not quite so evident. Although this is the jubilee year, Post Office names were conspicuous by their absence from the Queen's Birthday honours, and even such ardent reformers as Mr. Henniker Heaton, with an ignorance that is surprising, speak in contemptuous terms of the unimpressionable mind of the red-taped official.

The most scientific branch of the Post Office is unquestionably the telegraphic. Many fears were entertained that its efficiency would deteriorate under the supposed chilling influence of Government monopoly, but these fears have not been realized. Facilities have been increased, business has been developed, improvements have been introduced, new processes have not only been adopted but originated, and our Postal Telegraph Department unquestionably holds the most prominent position in the world at the present moment. The number of messages, which in 1869, the year before the transfer, amounted to 6,000,000, now reaches over 60,000,000. Duplex, quadruplex, and sexuplex methods have been made practical. The automatic system of Wheatstone,